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# RESEARCH TRIANGLE INSTITUTE

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Second Quarterly Technical Report

# INVESTIGATION OF LOW TEMPERATURE MULTILEVEL DIELECTRICS FOR APPLICATION FOR RADIATION TOLERANT, SUBMICRON-SCALED IC TECHNOLOGY

Period Covered: 1 April 1989 to 30 June 1989

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## 1.0 INTRODUCTION

The following report details the progress on ONR Contract Number N-00014-86-0421 during the period from 1 April 1989 to 30 June 1989. This program entails a joint effort between Research Triangle Institute and North Carolina State University. Funding is being provided by the Innovative Science and Technology Office of the Strategic Defense Initiative.

During this quarter work has proceeded in mapping out the nitride deposition parameter space. This work is described in section 2.0. The new ultra-high purity reactor is on line and in use. Nitride results showing a 2 order of magnitude improvement over results from the original reactor are given. This work is described in section 3.0. Section 4.0 includes the summary and preview.

# 2.0 NITRIDE DEPOSITION WORK

A great deal of effort has been put into characterization of the remote plasmaenhanced nitride deposition process using No as the nitrogen source. The data base
listing in Appendix A includes deposition conditions and characterizations of the deposited films. The deposition variables include temperature, pressure, and gas flow rates.

The characterizations include deposition rate, etch rate, refractive index (from elipsometry), dielectric constant, infrared data, flatband shift, and hydrogen content.

This data base allows correlation of data according to any combination of parameters
in the data base. This function can be used to verify the possibility of improbability of
various suspected correlations. This capability is illustrated in Figure 1, "Growth rate
vs. Silane Flow Rate". Note the parameters listed under the title.

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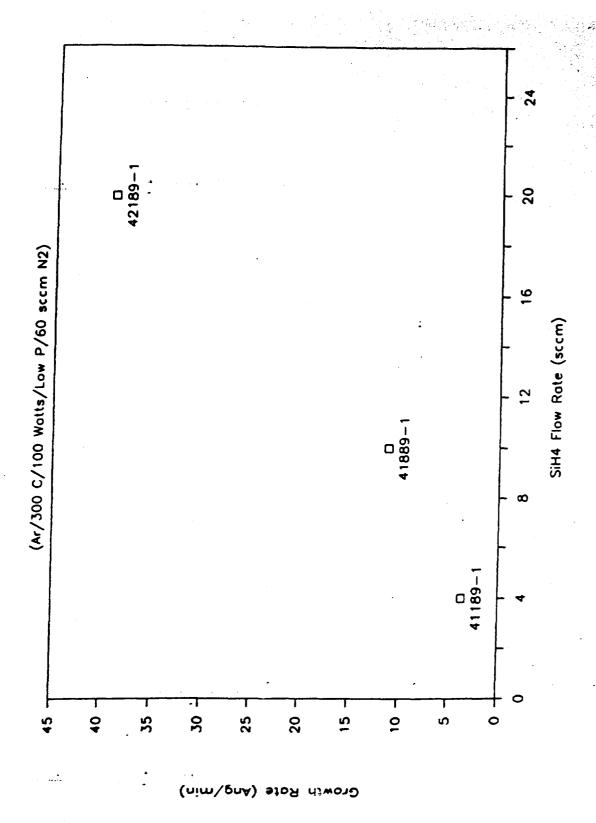


FIGURE 1: Growth rate vs. SiH4 rate.

# 3.0 NEW ULTRA-HIGH PURITY REMOTE PLASMA DEPOSITION SYSTEM

A new ultra-high purity deposition system is now on line and operating at RTL This reactor takes advantage of the insights we have gained into the oxide and nitride deposition processes. The reactor has an all quartz deposition region for high purity. and a long flow tube type design to minimize eddie current flows. The all-quartz construction of the reaction zone allows us to use external heaters to heat the sample. which greatly simplifies the internal construction of the reactor and eliminates many sources of contamination. The reaction zone is heated with infra-red lamps. This radiation should couple very well into any water-related byproducts and help to drive them off of the reactor walls so they can be transported out of the reaction zone. The gas delivery lines are very short to minimize contamination from the lines, and each gas will be filtered at its injection point with a .05 micron filter. All-metal sealed leak valves are used for flow control so that the gas lines are entirely UHV compatible and bakeable. The system provides much latitude for adjustment of sample position and plasma region position. We believe this system will allow us to make major strides in the development of high-quality, highly reliable dielectrics.

Already the new system is proving its viability in the area of nitride deposition. The charge to breakdown data shown in Figure 2 is from a nitride deposited at 300 °C in the new system. This nitride film passed a total charge of over 400 C/cm<sup>2</sup> before breaking down. The total voltage shift was less than 0.1 Volt. The best nitride films

out of the original reactor had total charge to breakdown values, of 1 C/cm<sup>2</sup>. This exciting new result we attribute to the overall improved purity in the new reactor.

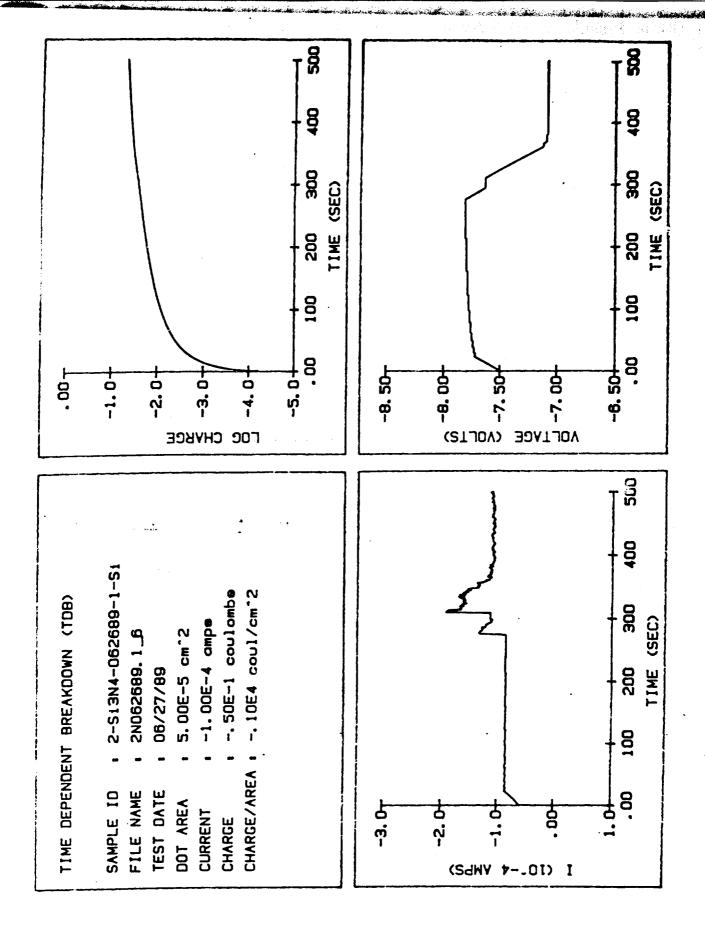


FIGURE 2: Time dependent breakdown measurement for  $Si_3N_4$  film ( $\sim$  10 nm thick) deposited at 300 °C using the new ultra-high purity reactor.

## 4.0 SUMMARY AND PREVIEW

During this quarter the nitride deposition process parameter space has been intensively investigated. The data has been entered into a data base for convenient evaluation. Possible correlations of deposition parameters with material characteristics are being evaluated.

The new ultra-high purity deposition system has been brought on line and is being exercised. This system has already shown the capability of improving the quality the deposited materials in the nitride deposition area. A Si<sub>3</sub>N<sub>4</sub> film has been deposited which passed 400 C/cm<sup>2</sup> before breaking down. This result is a 2 order of magnitude improvement over results obtained in the original system.

During the next quarter we will report additional results from deposition studies onducted using the new ultra-high purity reactor. These studies will include both vide and nitride depositions.

APPENDIX A

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Femp.   Power   Press.   Ar   He   N2   SiH4   N2   He   Ar/He   Simularian   Signatura   Signatura				2	Plasma F	<b>9</b>	<u></u>	Ring Fee	ā			E
(C) Watts)         Torr)         (sccm)         (sccm)           300         30         Low P         400         10         60         100           300         30         Low P         400         10         60         100           300         30         Low P         400         2         60         100           300         30         Low P         400         4         60         100           300         30         Low P         400         4         60         100           300         100         Low P         400         4		remp.	Power	Press.	Ā		Z	SiH4	N2	H2	Ar/He	Thickness
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300         30         0.20         500         40         10           300         30         0.10         500         40         10           300         30         0.10         500         40         10           300         30         0.10         200         40         10           300         30         0.10         200         40         10           300         30         0.10         200         40         10           300         30         0.04P         400         10         10           300         30         Low P         400         10         10           400         30         Low P         200         10         10           400         30         Low P         200         10         10           400         30         Low P         200         4         10           400         30         Low P         200         10         10           400         30         Low P         200         40         10           350         100         Low P         200         10         10           350	50589-2	300	30	010		000		10	10			565.0
300         30         0.10         500         40         10         10           300         30         0.10         200         40         10	50589-3	8	900	200		2000	2	4				250.0
300         30         0.10         200         40         10           300         30         0.10         100         40         10           300         30         0.10         200         40         10           300         30         0.10         200         40         10           300         30         Low P         400         10         10           400         30         Low P         400         10         10           400         30         Low P         200         10         10           400         30         Low P         200         40         4           400         30         Low P         200         40         4           400         30         Low P         200         10         10           400         30         Low P         200         10         10           350         100         Low P         200         10         10           350         200         Low P         200         10         10         11           350         200         Low P         200         100         4         11	50889-1	380	8	0.10		000	9 9	10				605.0
300         30         0.10         100         40         10           300         30         0.10         200         40         10           300         30         Low P         400         10           300         30         Low P         400         10           300         30         Low P         400         10           400         30         Low P         200         10           400         30         Low P         300         40           400         30         Low P         200         10           350         100         Low P         200         10           350         200         Low P         200         10	50889-2	300	30	0.10		350	\$	10	1			410.0
300         30         0.10         200         40         10           300         30         Low P         400         40         10           300         30         Low P         400         10           300         30         Low P         400         10           400         30         Low P         200         10           400         30         Low P         200         40           400         30         Low P         200         10           350         Low P         200         10         10           350         Low P         200         10         10           350         Low P         200         100         10           350         Low P         200         100         4           350         Low P         200         100         10 <t< th=""><td>50889-3</td><td>300</td><td>30</td><td>0.10</td><td></td><td>3 2</td><td>2 6</td><td>2 5</td><td></td><td></td><td></td><td>230.0</td></t<>	50889-3	300	30	0.10		3 2	2 6	2 5				230.0
300         30         0.30         200         40         10           300         30         Low P         400         10           300         30         Low P         400         10           400         30         Low P         200         10           400         30         Low P         200         10           400         30         Low P         200         40           350         Low P         200         10         10           350         Low P         200         10         10           350         Low P         200         100         10           350         Low P         200         100         10           350         Low P         200         100         4           350         Low P         200         100         4           350         Low P         200         100         4           350         <	50989-1	300	30	0.10		38	Ç	₽,	1			100.0
300         30         Low P         400         10           300         30         Low P         400         10           400         30         Low P         200         10           400         30         Low P         200         10           400         30         Low P         200         40           400         30         Low P         200         40           400         30         Low P         200         40           350         100         Low P         200         10         1           350         200         Low P         200         100         4         1           350         200         Low P         200         100         4         1           350         200         Low P         200         100         4         1           350         200         Low P         500         1	50989-2	300	ဆ	0.30		3 5	3 4	4	1			160.0
300         30         Low P         400         10           300         30         Low P         400         10           400         30         Low P         200         10           400         30         Low P         300         40           400         30         Low P         200         40           400         30         Low P         200         40           350         100         Low P         200         10         1           350         200         Low P         200         100         4         1           350         200         Low P         200         100         4         1           350         200         Low P         200         100         4         1           350         200         Low P         500         10         10         1	51089-1	300	30	LOWP		33		01				0.0
300         30         Low P         400         10           300         30         Low P         200         10           400         30         Low P         300         40           400         30         Low P         200         40           400         30         Low P         200         40           350         100         Low P         200         10         1           350         200         Low P         200         10         1           350         200         Low P         200         10         1           350         200         Low P         200         100         1           350         200         Low P         200         100         4         1	51089-2	300	30	Low P		3 5		01	2			555.0
300         30         Low P         200         10           400         30         Low P         300         40           400         30         Low P         200         40           400         30         Low P         200         40           400         30         Low P         200         40           350         100         Low P         200         100         10           350         200         Low P         200         100         4         1           350         200         Low P         200         100         4         1           350         200         Low P         500         100         4         1	51089-3	300	30	d wo		3 8		2	20			315.0
400         30         Low P         300         10           400         30         Low P         300         40           400         30         Low P         200         40           400         30         Low P         200         40           350         100         Low P         200         10         1           350         200         Low P         200         10         1           350         200         Low P         200         10         1           350         200         Low P         200         100         1           350         200         Low P         200         100         4         1           350         200         Low P         200         100         4         1           350         200         Low P         500         100         4         1	51189-1	300	8	d wo		3 8		0 :	â			307.5
400         30         Low P         300         4           400         30         Low P         200         40         4           400         30         Low P         200         40         4           350         100         Low P         200         10         1           350         200         Low P         200         10         1           350         200         Low P         200         10         1           350         200         Low P         200         100         10           350         200         Low P         200         100         4         1           350         200         Low P         500         100         4         1	51189-2	800	30	d wo		3 8		0	-l 04			464.0
400         30         Low P         200         40           400         30         Low P         200         40         40           350         100         Low P         200         10         10         11           350         100         Low P         200         10         11         11           350         200         Low P         200         100         10         11           350         200         Low P         200         100         4         11           350         200         Low P         200         100         4         11           350         200         Low P         500         100         4         10	51189-3	8	30	J WO		35		10	ş			225.0
400         30         Low P         200         40         40           350         100         Low P         200         100         10           350         100         Low P         200         10         10           350         200         Low P         200         10         10           350         200         Low P         200         10         4           350         200         Low P         500         10         4	51289-1	400	30	d wo		36	١	4	9			
350         100         Low P         200         100         10           350         100         Low P         200         10         10           350         200         Low P         200         10         10           350         200         Low P         200         100         10           350         200         Low P         200         100         4           350         200         Low P         500         10         4	51289-2	400	30	Low P		36	2	4 (				175.0
350         100         Low P         200         100         10           350         200         Low P         200         10         10           350         200         Low P         200         100         10           350         200         Low P         200         100         4           350         200         Low P         500         10         4	51589-1	350	100	LOWP		200	9	2	8			558.0
350         200         Low P         200         10           350         200         Low P         200         100         10           350         200         Low P         200         100         4           350         200         Low P         500         10         4	51589-2	350	2	LOWP		200	3	2				0.798
350         200         Low P         200         100         10           350         200         Low P         200         100         4           350         200         Low P         500         10         4	51589-3	350	200	d wo		38		2	180			588.0
350 200 Low P 200 100 4 350 200 Low P 500 100 4	51689-1	350	200	Low P		3 8	1	2	8			913.0
350 200 Low P 500 100 10 .	51689-2	350	200	Low P		200	3 5	02				570.0
101	51689-3	350	200	Low P		3 5	3	4	8			519.0
	ı							10	8	7		820.5

2										
Sample	Grown Co	Conditions		Plasma Feed	pee_		Ring Feed	ס		Film
	Temp.	Power	Press.	Ā	¥	NS	SiH4	N N	¥	Ar/He Thickness
	( <u>C</u>	Watts)	(Torr)	(sccm)			(sccm)			Æ
51789-1	320	200	Low P		200	8	101	-		2000
51789-2	400	200	Low P		200		٩	٤		990.0
51789-3	400	280	L	200			; 	3 5		07/20
51889-1	300	8			-		•	3		473.0
6 000 3							10	04		533.0
2-60010	3	82	0.08	200			10	04		1014.0
51889-3	300	28	0.08	905	-		ç	8		2
51989-1	<b>4</b> 00	200	0.08	300	-   		o c	3 5		
51989-2	004	200	0.07	300			01	2 2		
51989-3	400	200	0.08	300			9	3 2		
								3		

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

Sample	<u>.</u>	Growth	_	Etch		Optical	Refract	Refract Concentration	ation
	Time	Rate	Thickness	Time	Rate	Thickness	Index	H-ig	
	(min)	(Amin)	€	(sec)	(A/sec)	(4)	(6)	; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ;	
32889-2	45	10.92	96.5	3	1930	(11)		2-11-2	
32989-2	6	6.50	77.5	2	15.50	0.750	7.7		1.94E+22
33189-2	120	8			13.30	0.000	20.7		2.16E+22
40389-2	120	13.32	o da	0	30.0	442.5	1.802		
40689-2	180	1 78	236.0	0 6	16.00	1455.5	1.812	1.00E+21	1.33E+22
40789-1	180	7 37	0.554	2	23.50	239.0	2.000		
40789-2	340	500	0.061-		ERR	1342.5	1.668		1.09E+22
41089-1	250	2.24	455.0	5	91.00	567.3	1.713		1.57E+22
41189-1	250	3 6		5	0.00	280.0	2.000		
41189-2	200	3.00	57.5	120	0.48	859.3	1.899		5.63E+21
41280-1	3	3.0	75.0	30	2.50	0.699	1.819		5.50F+21
1000	20	3.58	228.0	30	7.60	608.5	1 809		6 17E-21
7-502-14	180	3.77	130.0	180	0.72	735.0	1.896		£ 165.21
1-80014	180	4.28	113.3	5	22.66	928.0	1 680		9.105+21
7-886-4	180	5.70	511.6	5	102 32	967.0	200.		8.40E+21
41489-1	180	2.56	461.0	3	92.20	0.700	70/1		7.08E+21
41789-1	180	2.83	45.0	, ,	96.20	0.200	1.820		1.80E+22
41889-1	120	11.25	3006	2 6	4.50	631.0	1.785		2.50E+22
41989-1		FRB		2	10.73	2342.0	2.000		
42189-1	9	39.00	30.0	0	90 9				
42189-2	180	5.39	450.0	, "	300	1904.5	2.000		5.32E+21
42489-1	120	16.67	400	, 4	00.00	0.290	1.727		1.13E+22
42489-2	120	22.92		7	00.00	1/19./	2.000		4.47E+21
42689-2	128	16.80	000	, ,	90 9				6.22E+21
50289-1	180	2.39		2	9.00	1/66.0	2.000		
50289-2	180	3.33	1	7	00.0				
50389-1	9	10.88		7	3 6	0.070	1.808		
50389-2	S.	25.65		?	3.0	0.400	1.747		
	3	7		<u>_</u>	800	758.0	1 743		

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

-									
Sample	<u>5</u>	Growth	Etch			Optical	Refract.	Refract. Concentration	ration
	Time		Thickness	Time	Rate	È	Index	I I	
	(min)	(√min)	€	(sec)	(A/Sec)	(4)	(3)		
50389-3	180	2.39		2	8		(1)	21112	
50489-1	120	6.25		, 4	8 8	4/4.0	7.790		
50589-1	06	6.28		, 4	8 8	793.0	1.803		
50589-2	180	1.39		,	300	384.5	1.801		
50589-3	120	5.04			ב ב	0.18	2.000		
50889-1	8	33.4			HAH	548.0	1.811		
50889-2	3	200			ERR	417.0	1.794		
50889-3	3 5	3.03			ERR	245.0	2.000		
50080_1	3 5	/0.1			ERR	156.0	2.000		
60000	200	0.89		5	00.0	250.0	2.000		
£1000 +	3	00.0		5	0.00	30.0	2.000		
1-80015	3	6.17		5	0.0	607.0	1.830		
2-60015	3	5.25		5	00.0	304.0	000		
51069-3	09	5.13		2	00.0	280.0	200		
51189-1	8	5.16		5	6	2007	3		
51189-2	9	3.75			3 8	0.40	1.826		
51189-3	180	00.0		2	3 6	233.0	2.000		
51289-1	210	0.83		, "	38	188.0	2.000		
51289-2	120	4.65		, "	3 8	245.0	2.000		
51589-1	8	6.30		2	3 6	228.0	1.845		
51589-2	8	6.53		,	0.00	967.0	1.867		
51589-3	180	5.07	360 8	200	0.00	288.0	1.860		
51689-1	8	6.33	9000	3	3.01	913.0	1.867		
51689-2	210	2.47		2	300	570.0	1.880		
51689-3	8	0 13	0 000	7	3.5	519.0	1.926		
		9	Z03.U	2	14.15	800.5	1 857		

Sample	Growth	WH	Etch			Optical	Refract.	Refract. Concentration	ation
	Time	Rate	Rate Thickness	Time	Rate	Rate Thickness	Index	[Si-H]	[H-N]
	(min)	(Amin)	€	(sec)	(Asec)	€	Ξ	cm-3	
51789-1	8	7.56		5	0.0	0.899	1.849		
51789-2	8	6.97		5	0.00	627.0	1.880		
51789-3	180	2.63	0.866	120	7.82	473.0	1.932		
51889-1	06	5.92			ERR	533.0	1.882		
51889-2	120	8.45	0.03	20	2.50				
51889-3	120	0.00			EAR				
51989-1	210	00:00			ERR				
51989-2	06	0.00			ERR				
51989-3	210	00'0			ERR				

31-May-89	01:44 PM			
Sample	Accum.	Flat-Band	<u>}-</u>	Epsilon-R
	Cab.	Voltage	Ledge	Si3N4
	ρF	Shift (V)	(Log !)	
32889-2				000
32989-2				8 8
33189-2				2 2
40389-2	125.0	-3 15	1 0E-07	300
40689-2	124.2	-1.40	1 0F-07	2 48
40789-1	140.0	-1.15	5.0E-08	10 10
40789-2	350.0	-2.00	1.0E-07	60.6
41089-1	335.0	-2.25		000
41189-1	218.0	-2.60	1.0E-08	10.47
41189-2	140.0	-15.60	1.0E-09	4.16
41289-1	223.0	-1.95	1.0E-08	7.80
41289-2	102.1	-21.50	1.0E-09	3.80
41389-1	295.0	-1.15	1.0E-08	12.46
41389-2	234.7	-1.60	1.0E-07	13.21
41489-1	298.0	-1.25	1.0E-07	7.55
41789-1	220.0	-1.60	1.0E-08	6.15
41889-1	138.0	-2.05	1.0E-07	10.22
41989-1	103.0	-1.25	1.0E-08	12.43
42189-1	115.2	-1.30	1.0E-07	14.79
42189-2	255.0	-1.30	1.0E-07	13.57
42489-1	150.0	-1.75	1.0E-07	16.46
42489-2	120.0	-2.20	1.0E-67	18.10
42689-2			1.0E-07	0.00
50289-1			1.0E-07	0.00
2-68200	218.0	-2.10	1.0E-07	7.17
50369-1	300.0	-1.60	1.0E-07	10.75
2-89cnc	370.4	-1.35	1.0E-07	14.83

Sample	Accum.	Flat-Band	<b>&gt;-</b> 1	I-V Epsilon-R
	Cap.	Voltage	Ledge	Si3N4
	рF	Shift (V)	(Log 1)	
50389-3	255.0	-1.72	1.0E-07	6.03
50489-1	127.0	-5.00	1.0E-09	5 22
50589-1	230.0	-6.30	1 0F-09	12.5
50589-2				2 6
50589-3				8 8
50889-1				000
50889-2				0.00
20889-3				00.0
50989-1	377.4	-3.10	5.0E-09	3.31
2-888-5				00.0
1-69010			1.0E-08	000
2-68010	307.1	-5.55	5.0E-08	5.31
51089-3	292.7	-5.15	5.0E-09	4 94
51189-1	251.0	-1.90	2.0E-08	8 30
51189-2	467.0	9.4	9.0E-11	200
51189-3	596.0	-5.30	9.0E-11	2 6
51289-1	469.0	-6.45	5.0E-07	4 50
51289-2	204.0	09.6-	3.0E-09	6.24
51589~1	195.3	-3.30	6.0E-08	507
51588-2	191.5	-3.08	6.0E-08	6 18
51589-3	133.0	-3.95	6.0E-08	99.9
21683-1	211.0	-3.45	8.0E-08	9.9
2-599:5	202.0	-15.00	1.0E-06	5.75
51669-3	157.8	-3.00	1.0E-07	7.10

Sample	Accient	7 1 1 1 1 1 1 1 1		
		rial-band	>-	I-V Epsilon-R
	Cap.	Voltage	Ledge	Si3N4
	pF	Shift (V)	(Log I)	
51789-1				0.00
51789-2	195.0	-3.55	8.0E-08	671
51789-3	182.0		5.0F-11	4 70
51889-1	206.0	-4.35	5 OF OB	20.5
51889-2			20.0	0.02
51889-3				8 8
51989-1				8 8
51989-2				8 6
51989-3				9 6